# Polarization-independent CP-odd Observable in $e^+e^-$ Chargino Production at One Loop

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We discuss CP violation in the process $e^+e^- \to \tilde{\chi}_i^+ \tilde{\chi}_j^-$ with unpolarized beams. When the scalars are heavy, the box-diagram results constitute a major part of the full result. However, there are situations when the vertex and self-energy corrections dominate over the box diagrams. We also comment on CP violation in the final chargino decay.

## 1 Introduction

We review recent work on CP violation in unpolarized $e^+e^- \to \tilde{\chi}_i^+ \tilde{\chi}_j^-$ [1, 2, 3]. Let us consider the process with unpolarized initial beams:

$$e^+(p_1) + e^-(p_2) \to \tilde{\chi}_i^+(k_1) + \tilde{\chi}_j^-(k_2). \tag{1}$$

The crucial point here is that for $i \neq j$ the charginos do not form a particle-antiparticle pair. Hence, while the initial state is in the c.m. frame odd under charge conjugation, the final state has no such symmetry. This leads to the CP-violating effect we discuss here.

## 2 CP violating observable

Under CP conjugation the $S$-matrix element $\langle \tilde{\chi}_i^+(\boldsymbol{k}_1), \tilde{\chi}_j^-(\boldsymbol{k}_2)|S|e^+(\boldsymbol{p}_1), e^-(\boldsymbol{p}_2)\rangle$ of the process (1) gets transformed into (up to a phase which is irrelevant for us):

$$\text{CP:} \quad \langle \tilde{\chi}_j^+(-\boldsymbol{k}_2), \tilde{\chi}_i^-(-\boldsymbol{k}_1)|S|e^+(-\boldsymbol{p}_2), e^-(-\boldsymbol{p}_1)\rangle, \tag{2}$$

which amounts to the following change in the cross section[a]: $\boldsymbol{p}_1 \leftrightarrow -\boldsymbol{p}_2$, $\boldsymbol{k}_1 \leftrightarrow -\boldsymbol{k}_2$, $m_i \leftrightarrow m_j$. Due to Poincaré invariance the *unpolarized* cross section $d\sigma_0$ may depend only on the masses $m_i, m_j$ and on two independent scalar variables, say, on Mandelstam's $s \equiv (p_1 + p_2)^2$ and $t \equiv (p_1 - k_1)^2$ which obviously do not change under C or P. Hence, if one sticks to the unpolarized part only, the CP transformation can be reduced to final-state chargino mass interchange: $m_i \leftrightarrow m_j$. Therefore, for equal-mass fermions in the final state ($i = j$) the unpolarized cross section is always P-, C- and CP-even[b]. In contrast, if the chargino species are different, CP-violating terms can arise even in the unpolarized cross-section. That is the effect we will consider, so unless otherwise stated the final-state chargino masses are taken

[a] Of course, the coupling constants at vertices with charginos should be considered as functions of the chargino masses $m_i, m_j$, or, better, the mass indices $i, j$.

[b] The famous forward-backward asymmetry term in the *unpolarized* cross-section of, say, $e^+e^- \to \mu^+\mu^-$ scattering, which is often referred to as parity violating, in fact only indicates the presence of a parity violating term in the interaction, the unpolarized cross-section itself being, of course, P-even.

non-equal. The polarization-dependent CP-violating observables at one-loop order require more involved analysis and will not be discussed here.

Calculations show that the tree-level cross section (polarized and unpolarized) of the process (1) is CP even [4], but CP-odd terms do arise in the one-loop contributions. Therefore, a natural experimental observable to consider is the ratio

$$\frac{d\sigma_0^{\rm odd}}{d\sigma_0}\ , \tag{3}$$

where $d\sigma^{\rm odd}$ is the CP-odd part of the corresponding cross-section:

$$d\sigma_0^{\rm odd} = \frac{1}{2}\Big[d\sigma_0 - d\sigma_0^{\rm CP}\Big], \quad d\sigma_0^{\rm CP} \equiv d\sigma_0\Big|_{m_i\leftrightarrow m_j}. \tag{4}$$

As just mentioned, the CP violation first enters at one loop, thus, to estimate the effect one should calculate $d\sigma_0^{\rm odd}$ at the one-loop level. On the other hand, in most of the kinematical regions far from any resonance, one can expect (see, e.g. [5, 6, 7, 8]) that the tree level gives a reasonable approximation to $d\sigma_0$ in the denominator of Eq. (3). So, we will deal only with the ratio

$$A_{\rm CP} = \frac{d\sigma_0^{\rm odd}\big|_{\rm 1\ loop}}{d\sigma_0\big|_{\rm tree}}\ . \tag{5}$$

## 3 Box diagrams vs. full one loop contribution

In [2] partial one-loop calculations were provided for the case of complex higgsino mass parameter $\mu$. A limitation of that analysis was that it was performed in the heavy slepton limit, and furthermore, all one-loop triangle vertex corrections to (5) were dropped. The observed effect turned out to be of the order of a couple of percent[c], depending on the chosen MSSM parameters and the kinematics. As explained in [2], this calculation was done just to make sure that the observable does not vanish, while its magnitude should be estimated from complete one-loop results.

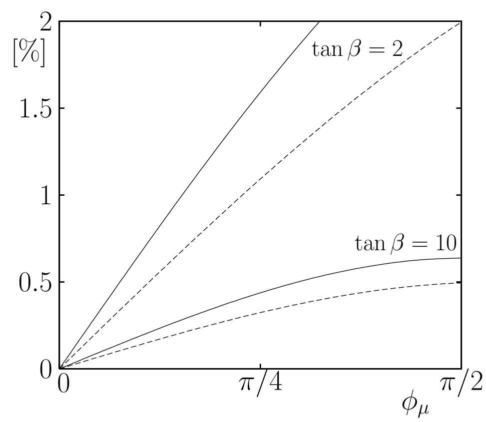


Figure 1: Box-only contribution (dashed lines) vs. full one-loop result (full lines) in the heavy sfermions limit for $\tan\beta = 2$ and 10.

A full calculation has recently been performed [3]. The full result turns out to be of the same order as the box-only estimates. In Fig. 1 the “box-only” and full one-loop values of the observable (5) are plotted as functions of the higgsino phase $\phi_\mu$ for $\tan\beta = 2$ and 10. The other parameters are taken as: $\sqrt{s} = 600$ GeV, the polar scattering angle $\theta = \pi/3$, the Higgsino mass parameter $\mu = |\mu|e^{i\phi_\mu}$, $|\mu| = 300$ GeV, the SU(2) gaugino mass parameter $M_2 = 200$ GeV, the U(1) gaugino mass

[c]A factor of four was lost in the calculation.

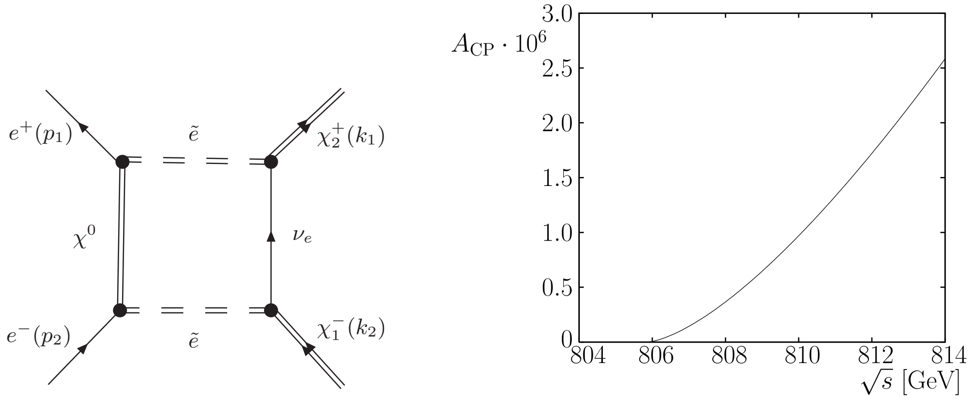


Figure 2: Selectron exchange box diagram and its contribution to (5). The selectron mass is 403 GeV.

parameter (taken to be real) $M_1 = 250$ GeV. The common SUSY breaking mass of the scalars (for the full one-loop calculation) is 1 TeV.

The qualitative agreement for the gauge box contribution alone can be (at least, partially) explained. Indeed, a closer look at the expression for the $Z$-boson exchange contribution (Eq. (4.1) in [2] gives the $D$-function part) shows, that only the imaginary part of the box integral can affect the observable. Since in the heavy slepton limit the position of the threshold singularity is high, the integral remains real in the kinematical region we consider. The selectron exchange box diagram provides a nice illustration: when we raise the c.m. energy above the selectron pair production threshold the selectron box diagram develops an absorptive part and its contribution to the asymmetry (5) is non-zero, see Fig. 3 (the selectron mass is 403 GeV). Similar statements can be made about most of the diagrams contributing to (5) at the one-loop order.

The above argument also indicates that in a scenario with lighter sparticles, other diagrams with vertex and self-energy corrections cannot be neglected, as demonstrated in [3]. It was also shown there that for the case of CP-violating origin in the top squark sector the box diagrams do not contribute and the CP asymmetry receives contributions only from vertex and self-energy diagrams.

## 4 Chargino decay: interference with CP violating effects

Since charginos are not stable particles and decay finally to leptons/quarks and the LSP, in a realistic experiment one has to take into account also chargino decays. On the other hand we know that also in chargino decays it is possible to obtain CP-violating effects at one-loop level [9]. Therefore one can worry if CP-violating effects in the decay would not cancel similar effects in the chargino production. However, a consideration similar to one presented in [2] helps here. As shown in that paper, at the one-loop level the observable (5) among other pieces contains the $D$-function integral.

To cancel such a contribution at any kinematical point, one needs a corresponding contribution from the final particle decay. So, the only way is the box diagram (e.g. the $Z$-exchange

box—see [2], Fig. 2) attached to one of the external legs. Even if the mass splitting between charginos is larger than $2m_Z$, the kinematic configuration of the box diagram in the decay is completely different from the one in the production, so the cancelation of different CP-odd contributions is in general not possible. This statement becomes trivial if the mass splitting is smaller than $2m_Z$ and no CP asymmetry arises in the decay due to double $Z$ exchange diagram. Moreover it is even possible to arrange parameters in such a way that no 2-body decay channels remain open for charginos and therefore no CP-odd contribution due to chargino decays enter in the full production+decay process, but still allowing for such contributions in the chargino production. Therefore we conclude that in general CP-odd effects in the production process can not be canceled by CP-odd effects in the decays of charginos.

## 5 Summary

We have demonstrated that the CP asymmetry built from unpolarized cross sections for non-diagonal chargino pairs in $e^+e^-$ annihilation can arise at the one-loop order.

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